Impact of cross section uncertainties on neutrino oscillation parameters

Pilar Coloma

Center for Neutrino Physics

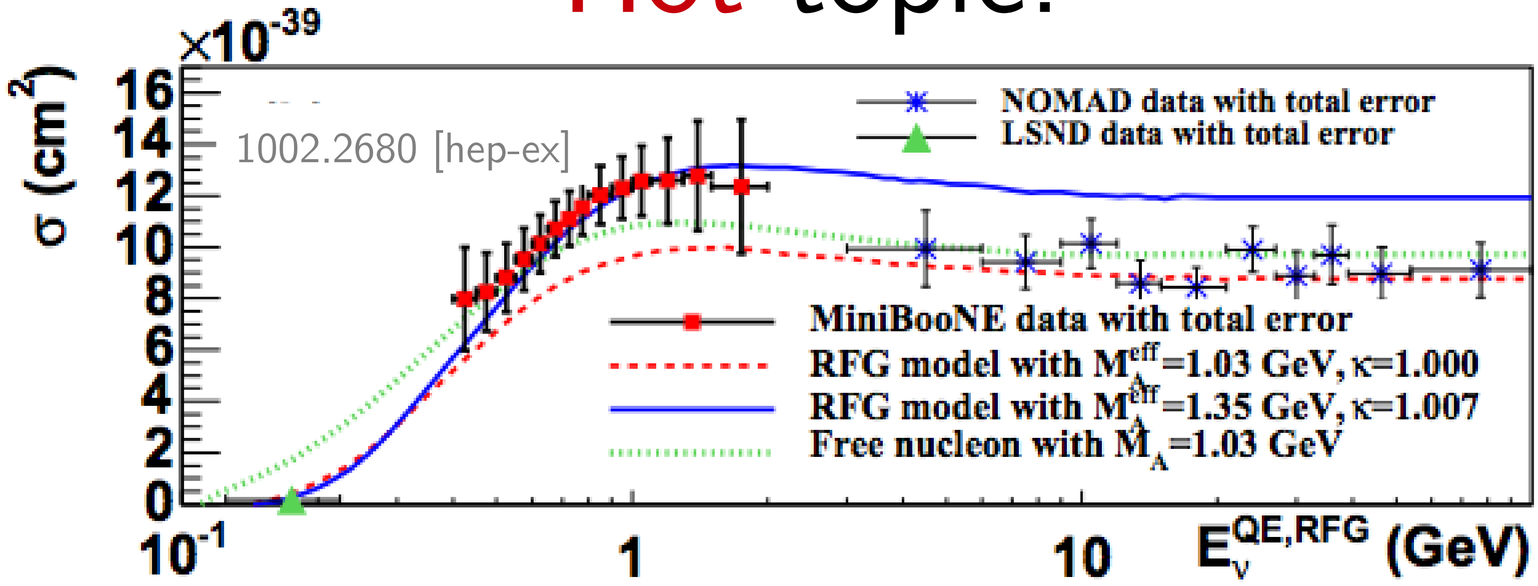
Virginia Tech

NuFact2013

Aug 19-24, 2013

IHEP, Beijing, China

Hot topic!



Gran, Nieves, Sanchez and Vicente Vacas, 1307.8105 [hep-ph], Nieves, Ruiz Simo, Vicente Vacas, 1302.0703 [hep-ph], Nieves, Sanchez, Ruiz Simo, Vicente Vacas, 1204.5404 [hep-ph], Nieves, Ruiz Simo, Vicente Vacas, 1106.5374 [hep-ph], Nieves, Ruiz Simo, Vicente Vacas, 1102.2777 [hep-ph], Lalakulich, Mosel and Gallmeister, 1208.3678 [nucl-th], Lalakulich, Gallmeister, Mosel, 1203.2935 [nucl-th], Lalakulich, Mosel, 1305.3861 [nucl-th], Lalakulich, Mosel, 1210.4717 [nucl-th], Martini Ericson, 1303.7199 [nucl-th], Martini, Ericson, Chanfray, 1211.1523 [hep-ph], Martini, Ericson, Chanfray, 1202.4745 [hep-ph], Martini, Ericson, Chanfray, 1110.0221 [nucl-th], Martini, Ericson, Chanfray, Marteau, 1002.4538 [hep-ph], Sobczyk, 1201.3673 [hep-ph], Golan, Graczyk, Juszczak, Sobzcyk, 1302.3890 [hep-ph] ... and many more!!

Outline

1) Intro: why so worried about systematics?

2) Impact of normalization uncertainties on CP violation searches

3) Shape uncertainties: reconstructed neutrino energy, final state interactions (FSI), 2p2h effects

4) Conclusions

The golden channel

The best chance to measure CPV is through:

$$P^{\pm}_{e\mu}(\theta_{13},\delta) = X_{\pm}\sin^2 2\theta_{13}$$

$$+ \boxed{Y_{\pm}\cos\theta_{13}\sin 2\theta_{13}}\cos\left(\pm\delta - \frac{\Delta m^2_{31}L}{4E}\right)$$

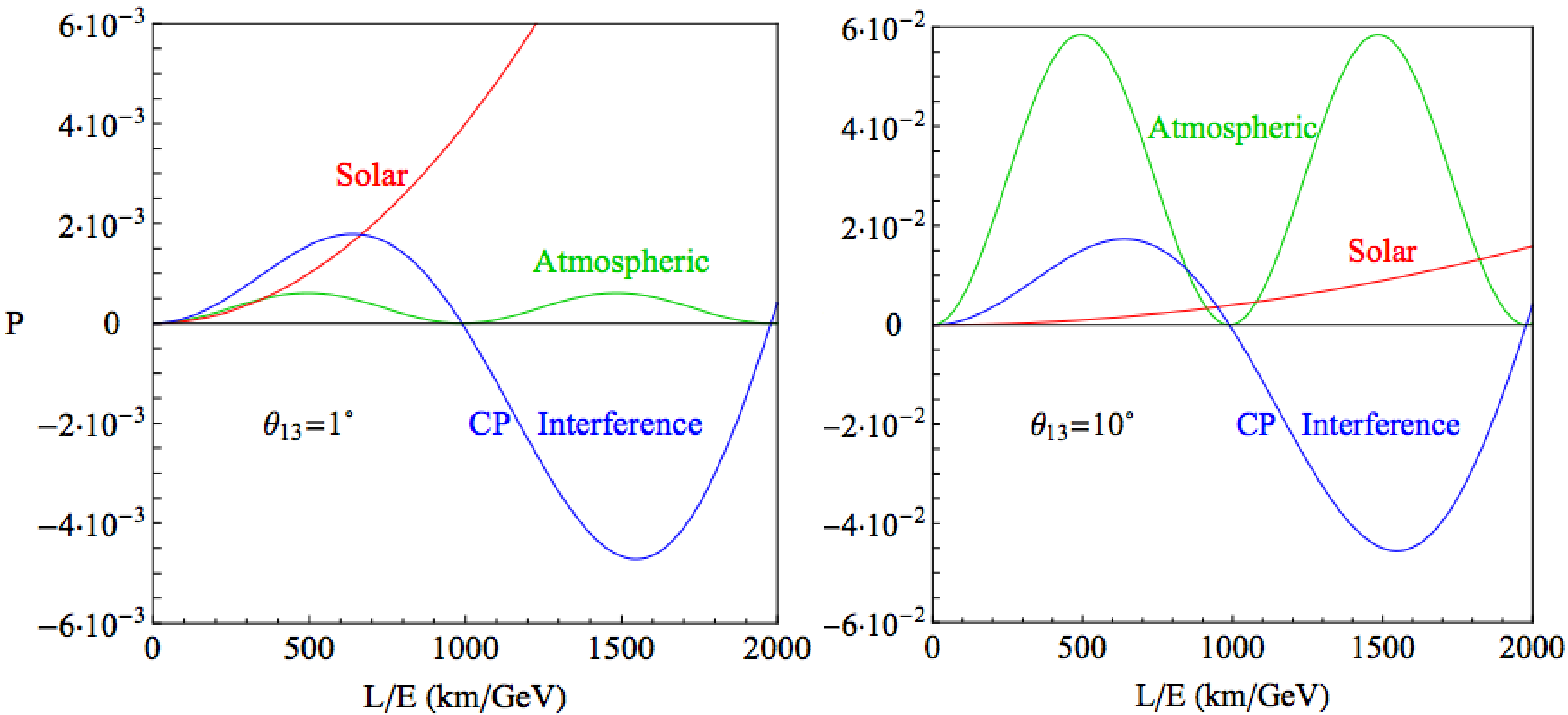
$$+ Z$$

Cervera et al., hep-ph/0002108

$$X_{vac} \propto \sin^2\left(\frac{\Delta m^2_{31}L}{4E}\right)$$

$$Y_{vac} \propto \sin\left(\frac{\Delta m^2_{31}L}{4E}\right)\sin\left(\frac{\Delta m^2_{21}L}{4E}\right)$$

Impact of systematics on CPV



Coloma and Fernandez-Martinez,
1110.4583 [hep-ph]

Near/Far cancellation?

$$N_\nu^{\alpha\to\beta}(L,E) \sim \epsilon(E) \times \sigma(E) \times \phi(E) \times P_{\alpha\beta}(L,E)$$

At reactor experiments, the cancellation of systematics between near/far detectors is very effective:

$$\frac{N^{ee}_{far}}{N^{ee}_{near}} \sim \cancel{\frac{\epsilon_e\sigma_e\phi_e}{\epsilon_e\sigma_e\phi_e}} P_{ee}$$

Discussed during
WG1+WG2
session on Tuesday
See also Kettel's talk

Near/Far cancellation?

$$N_\nu^{\alpha\to\beta}(L,E) \sim \epsilon(E) \times \sigma(E) \times \phi(E) \times P_{\alpha\beta}(L,E)$$

At reactor experiments, the cancellation of systematics between near/far detectors is very effective:

$$\frac{N^{ee}_{far}}{N^{ee}_{near}} \sim \cancel{\frac{\epsilon_e\sigma_e\phi_e}{\epsilon_e\sigma_e\phi_e}} P_{ee}$$

But an appearance experiment using accelerator neutrinos:

$$\frac{N^{\mu e}_{far}}{N^{\mu e}_{near}} \sim \boxed{\frac{\epsilon_e\sigma_e\phi_\mu}{\epsilon_\mu\sigma_\mu\phi_\mu}} P_{\mu e}$$

Discussed during WG1+WG2 session on Tuesday
See also Kettel's talk

Impact of systematics on CPV

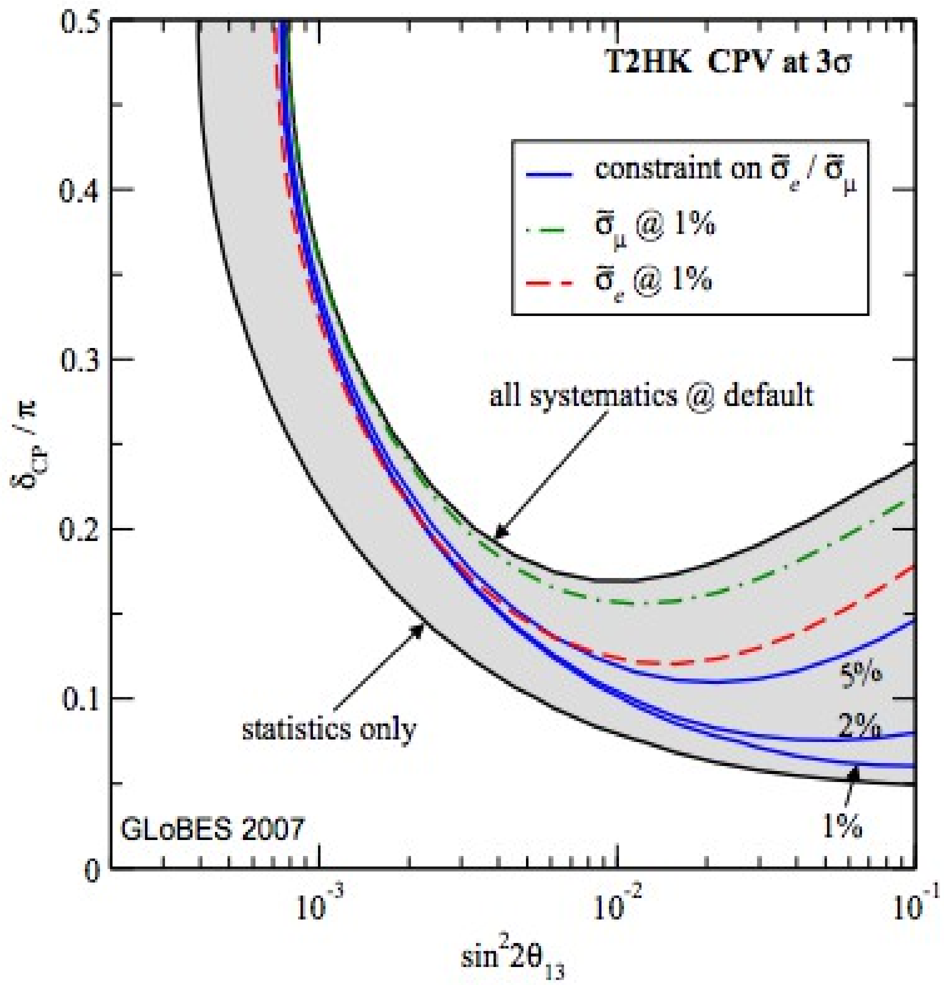
In order to do CP violation searches, we need an appearance experiment.

Possible ways to reduce the impact of systematics:

- put constraints on ratio between cross sections for different flavor

Day, McFarland, 1206.6745 [hep-ph]

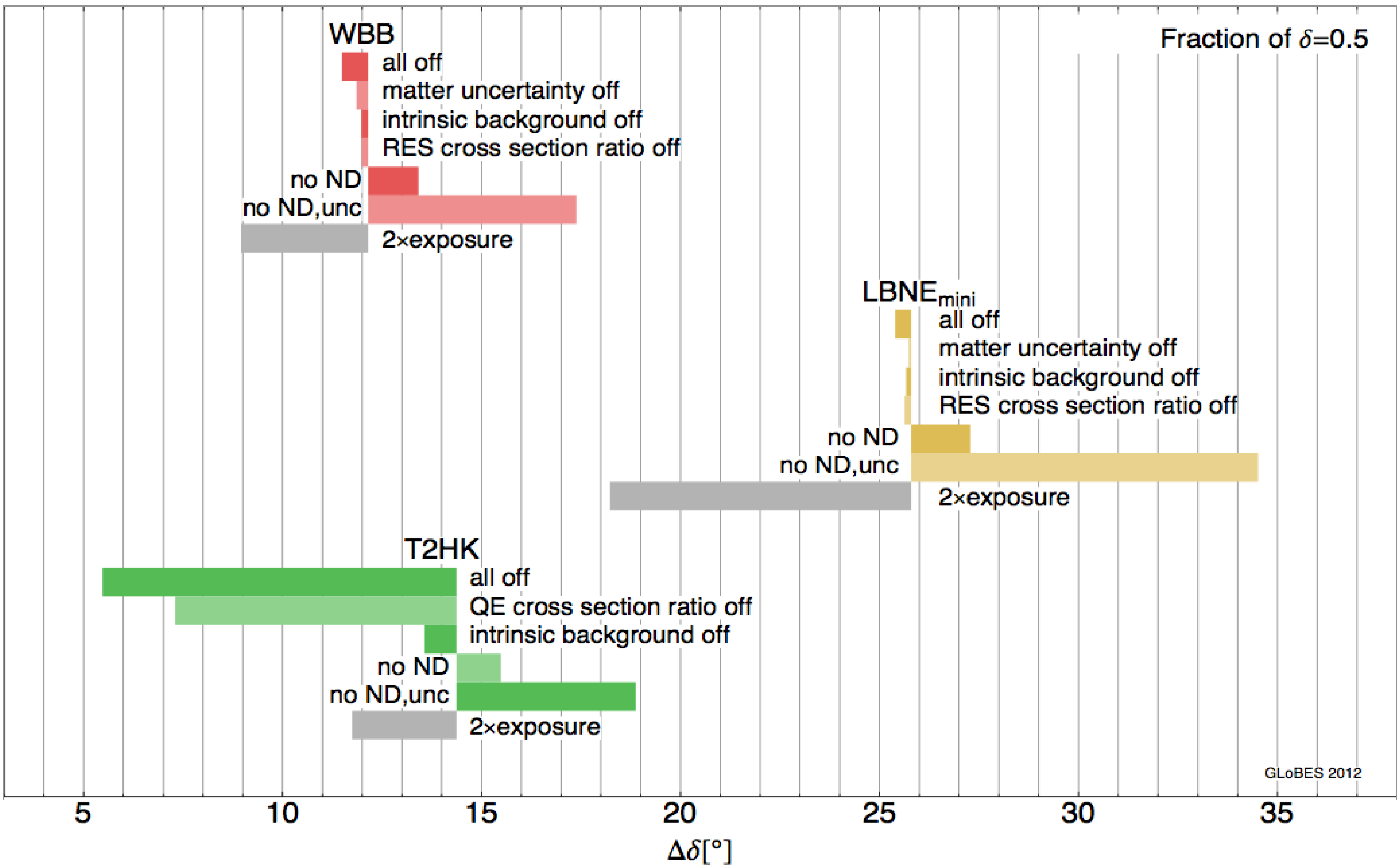
- do a combined fit using both appearance and disappearance data



Huber, Mezzetto and Schwetz, 0711.2950 [hep-ph]

See talks by Huber and Mezzetto

Precision, systematics and near dets



Coloma, Huber, Kopp, Winter, 1209.5973 [hep-ph]

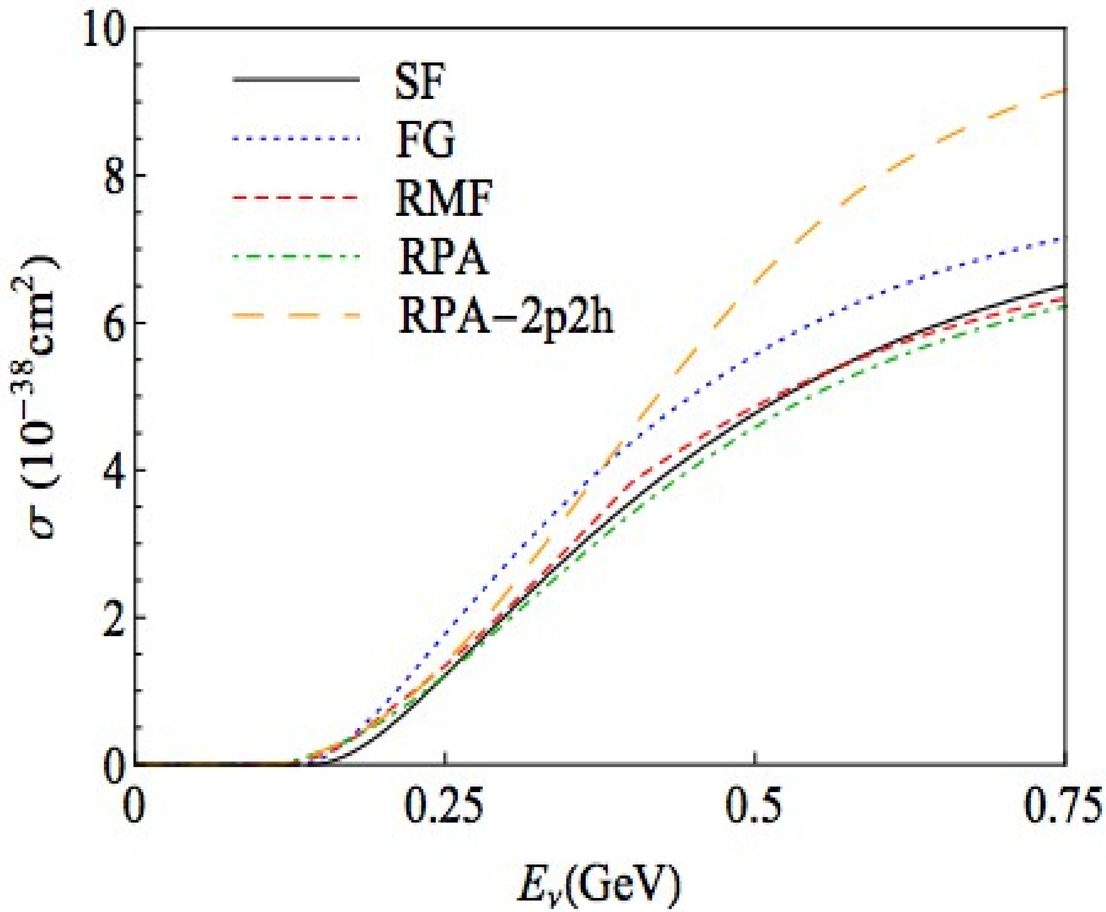
So far so good. However...

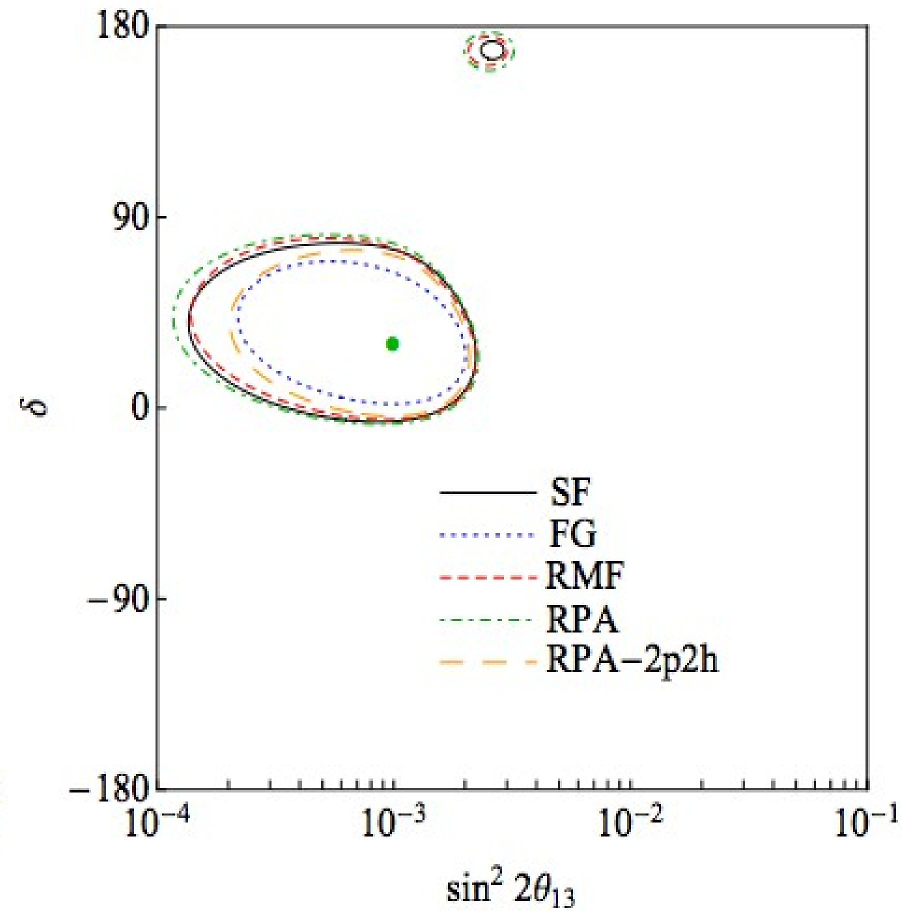
Certain assumptions have been made, in particular:

- Identical near and far spectra (unlikely, but we can dream...)
- No shape uncertainties on the cross section were considered $\rightarrow$ ie, perfect knowledge of nuclear model

If this is not the case, the situation can be far more complicated...I will focus on these effects in the rest of the talk

Cross section models





SF = Spectral Function

FG = Fermi Gas

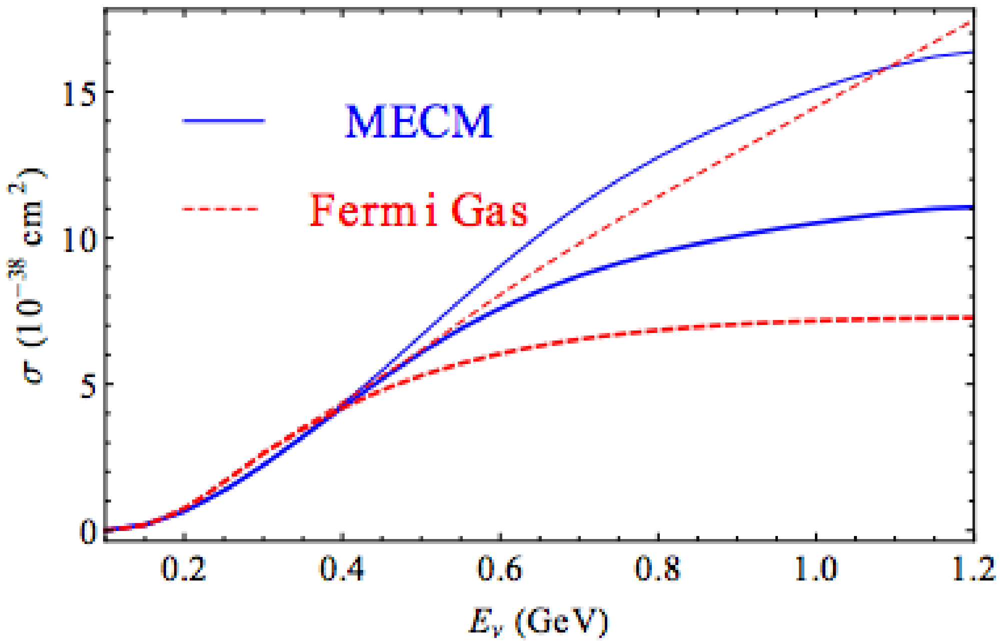
RMF = Relativistic mean field

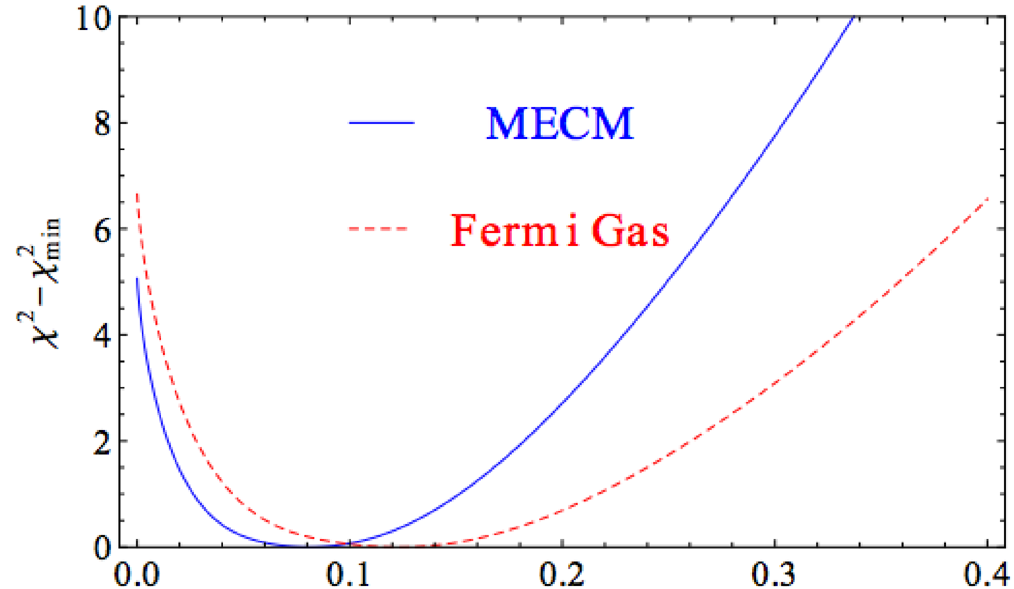
RPA = Random Phase Approximation

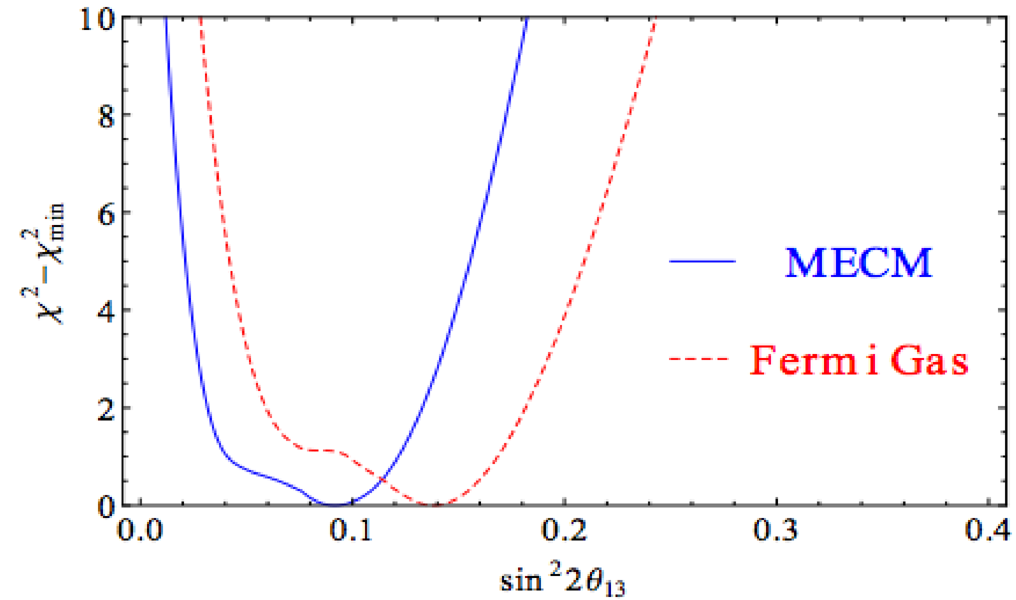
See Sobczyk's talk

Fernandez-Martinez, Meloni,
1010.2329 [hep-ph]

Cross section models



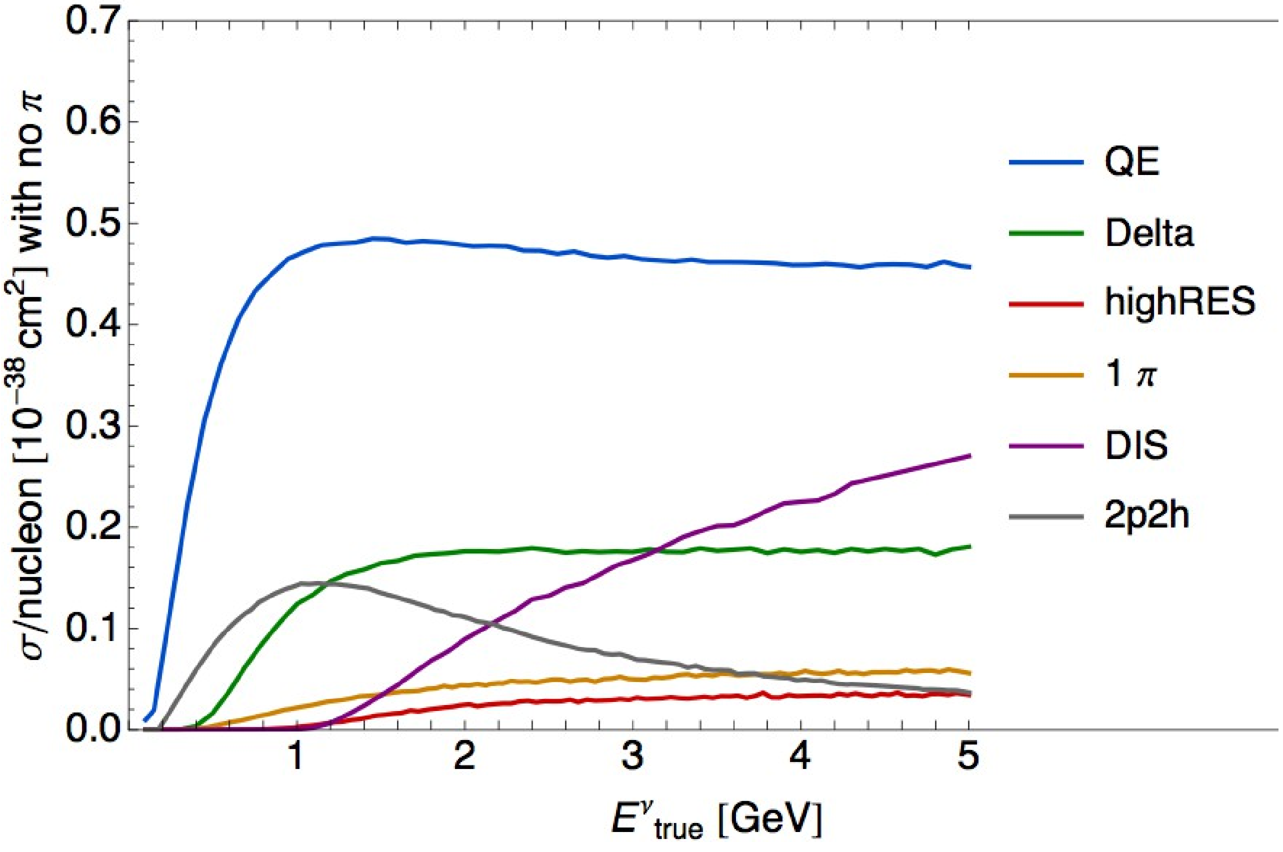


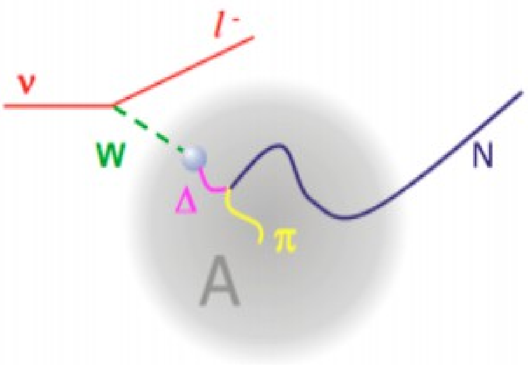


Martini, Meloni, 1203.3335 [hep-ph]

MECM model from Martini, Ericson, Chanfray, Marteau, 0910.2622 [nucl-th]

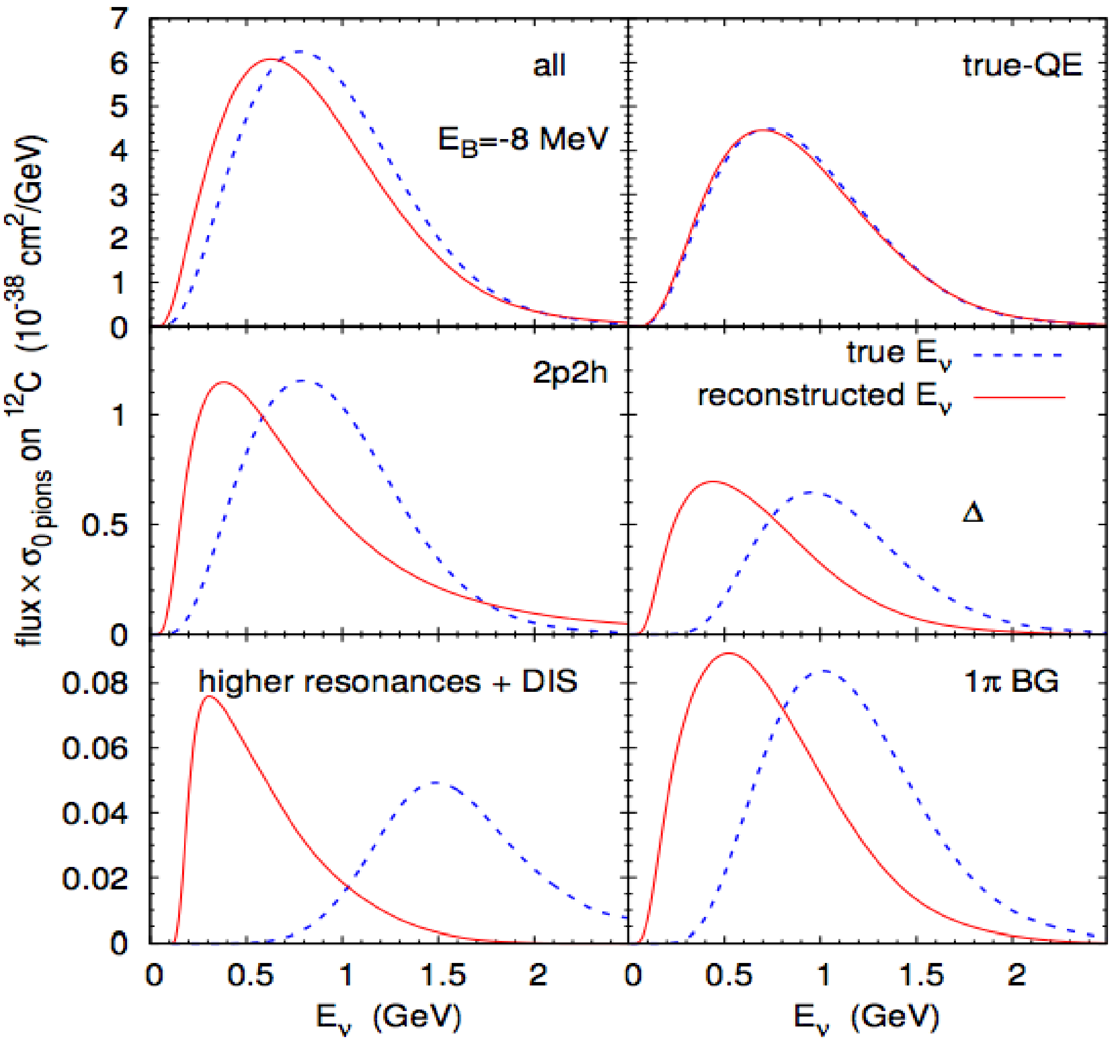
Final State Interactions

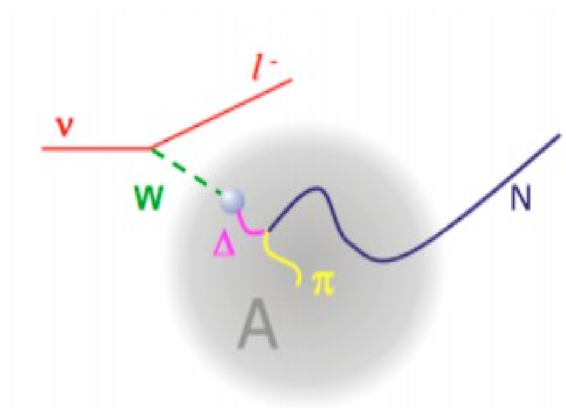




Lalakulich, Mosel and Gallmeister, 1208.3678 [nucl-th]

Energy reconstruction effects





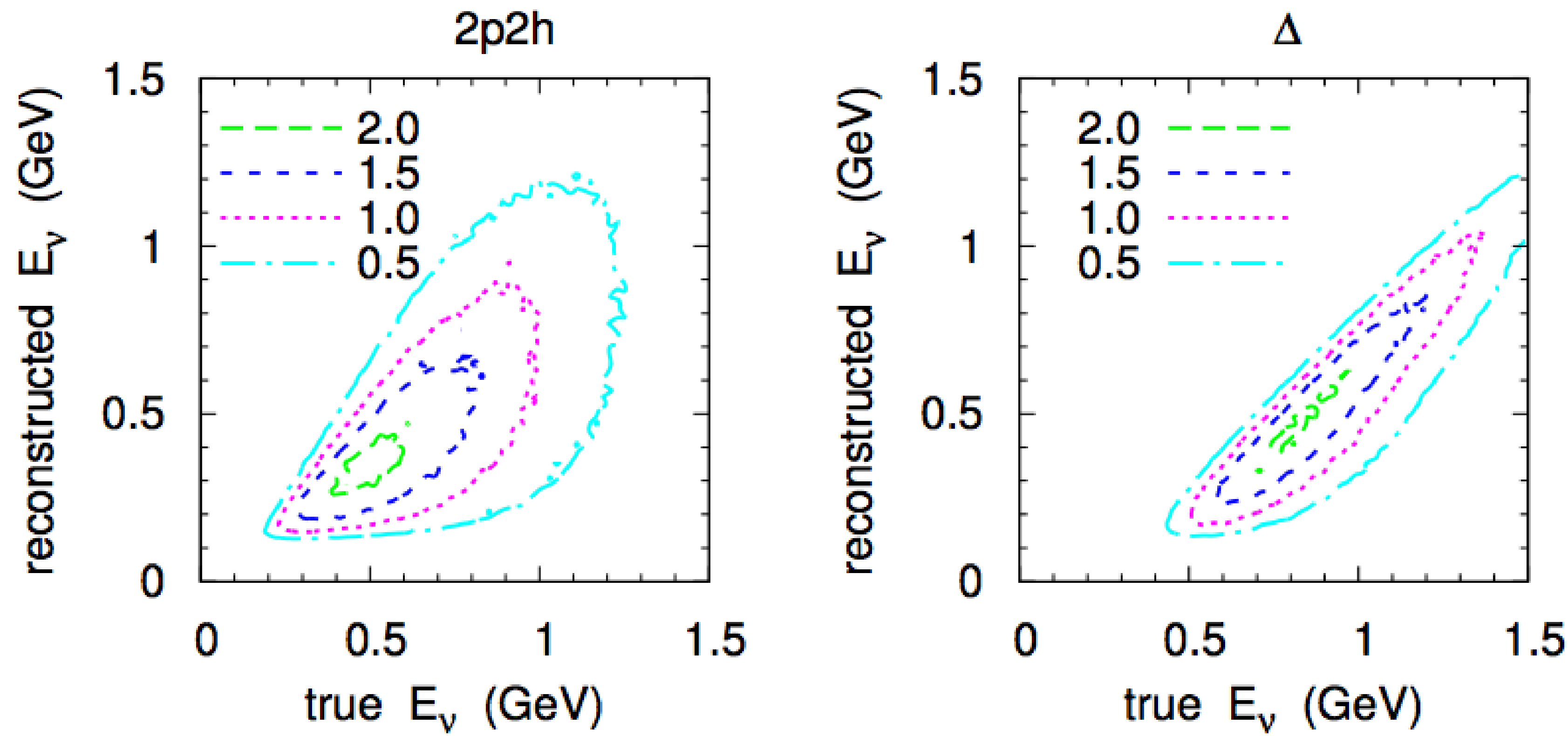
$$E_{\text{rec}} = \frac{ME_\ell - m_\ell^2/2}{M - E_\ell + |\vec{p}_\ell| \cos\theta_\ell}$$

Lalakulich, Mosel and Gallmeister, 1208.3678 [nucl-th]

Discussed in detail in WG2 during Monday and Tuesday

Energy reconstruction effects

These effects can be parametrized as migration matrices from true to reconstructed energy:



Lalakulich, Mosel and Gallmeister, 1208.3678 [nucl-th]

What would happen if we don't include these effects in the MC?

(...or, if we don't do it properly)

Toy model

- Super-Beam with peak energy around 0.6 MeV, L=295 km
  22.5 kton WC detector $\rightarrow$ QE events only (1-ring)

- Use migration matrix for ^{16}O produced with GiBUU

http://gibuu.physik.uni-giessen.de/GiBUU/wiki

Buss et al., 1106.1344 [hep-ph]

- Muon neutrino disappearance only $\rightarrow$ fit to atmospheric parameters
- Inclusion of bin-to-bin uncorrelated systematics (20%) to try to accomodate shape differences
- Ideal near detector assumed

Coloma and Huber, 1307.1243 [hep-ph]

Toy model

- Neglecting all FSI and multinucleon contributions, we can compute the number of events as:

$$N_i^{QE} = \sigma_{QE}(E_i)\phi(E_i)P_{\mu\mu}(E_i)$$

- However, in practice we will observe a different distribution at the detector, given by:

$$N_i^{QE-like} = \sum_j M_{ij}^{QE} N_j^{QE} + \sum_{non-QE} \sum_j M_{ij}^{non-QE} N_j^{non-QE}$$

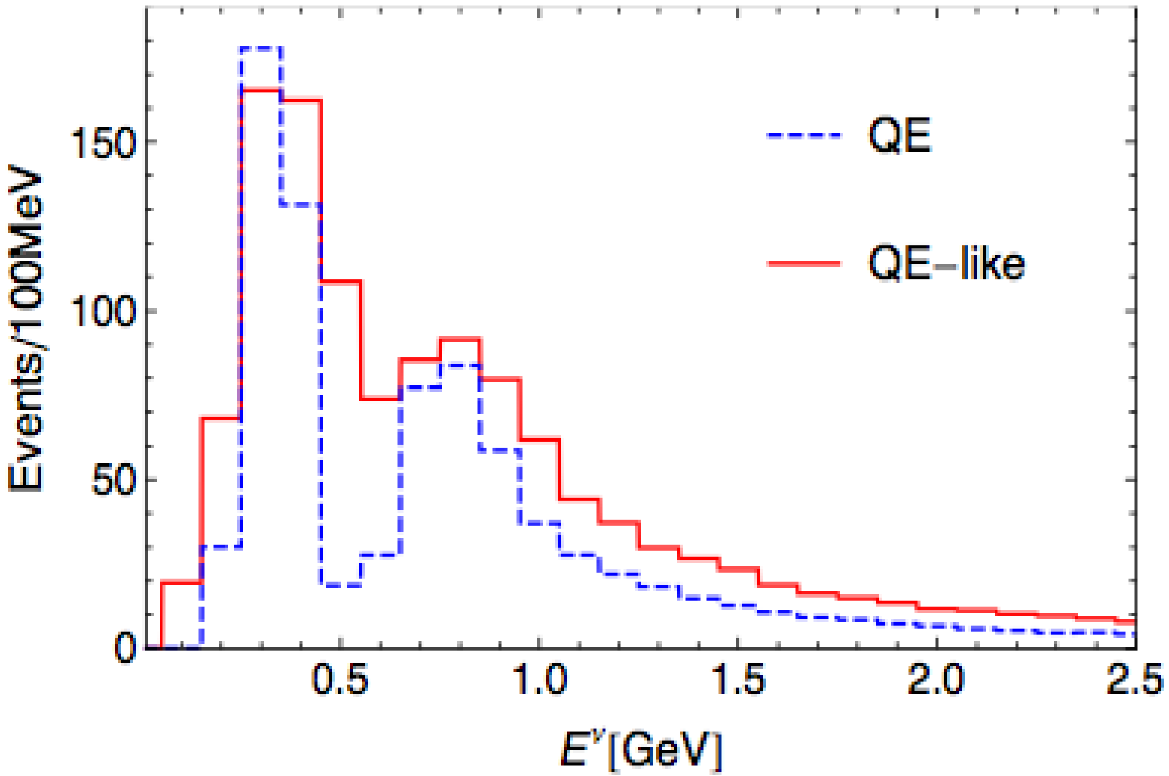
- However, an intermediate situation would most likely take place:

$$N_i^{test}(\alpha) = \alpha N_i^{QE} + (1-\alpha) N_i^{QE-like}$$

Coloma and Huber, 1307.1243 [hep-ph]

Toy model

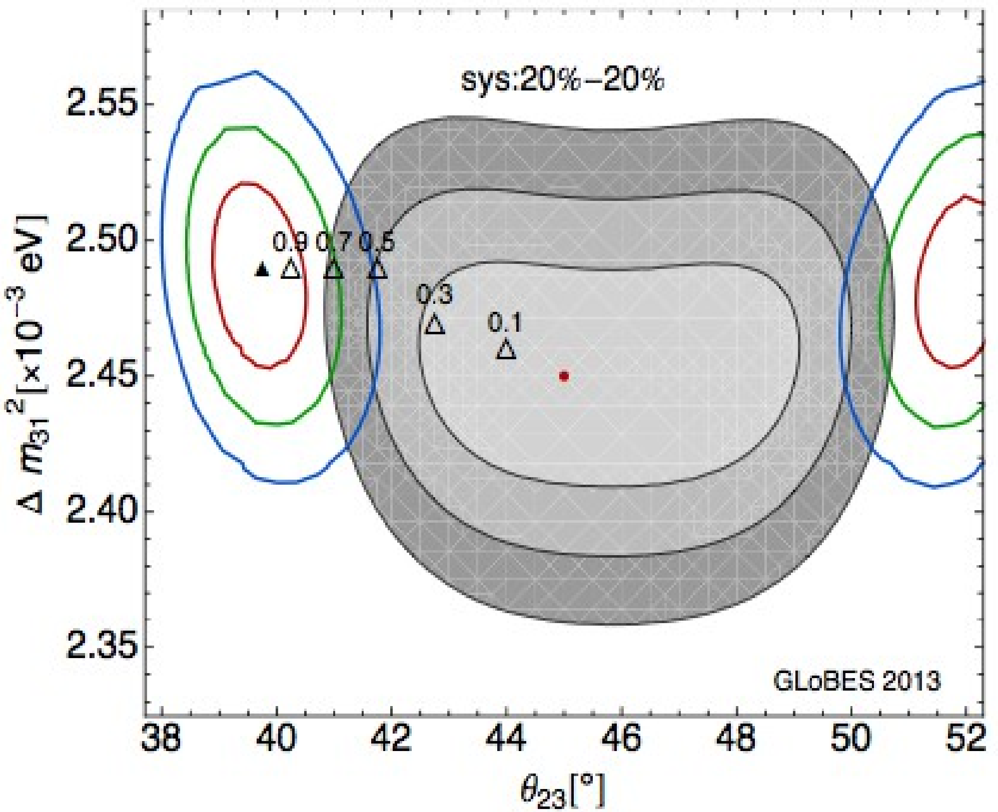
- As expected, very different distribution of events are obtained in each case:

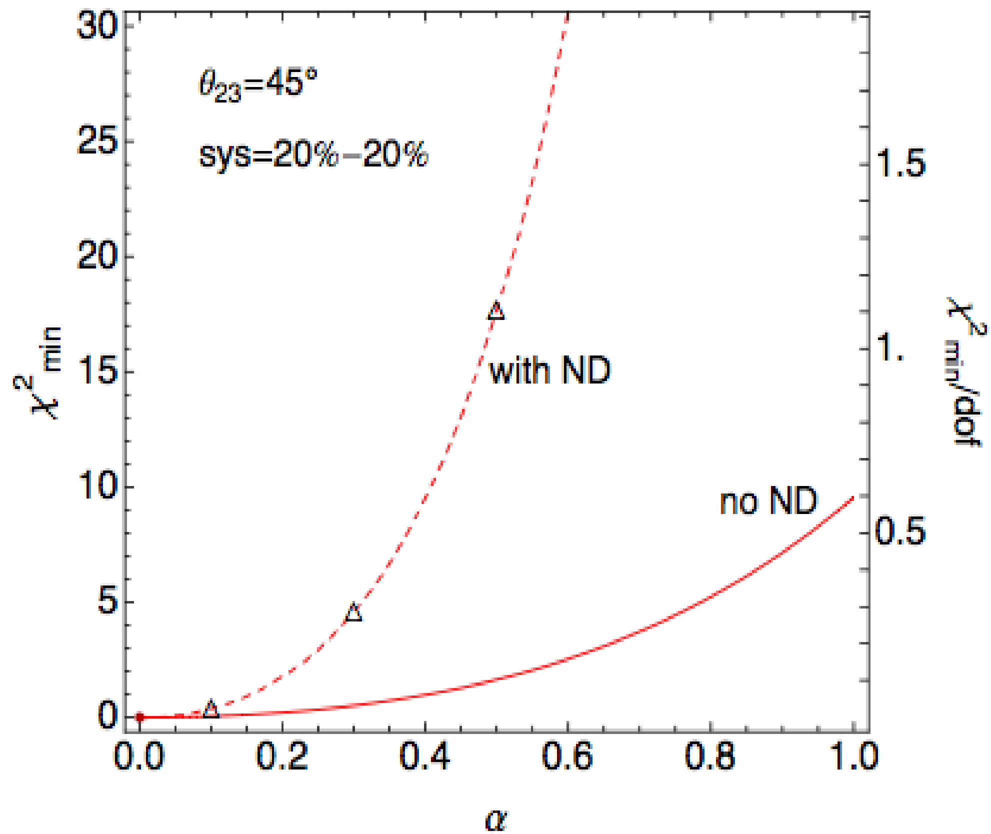


Coloma and Huber, 1307.1243 [hep-ph]

Toy model

$$N_i^{\rm test}(\alpha) = \alpha \times N_i^{QE} + (1-\alpha) \times N_i^{QE-like}$$

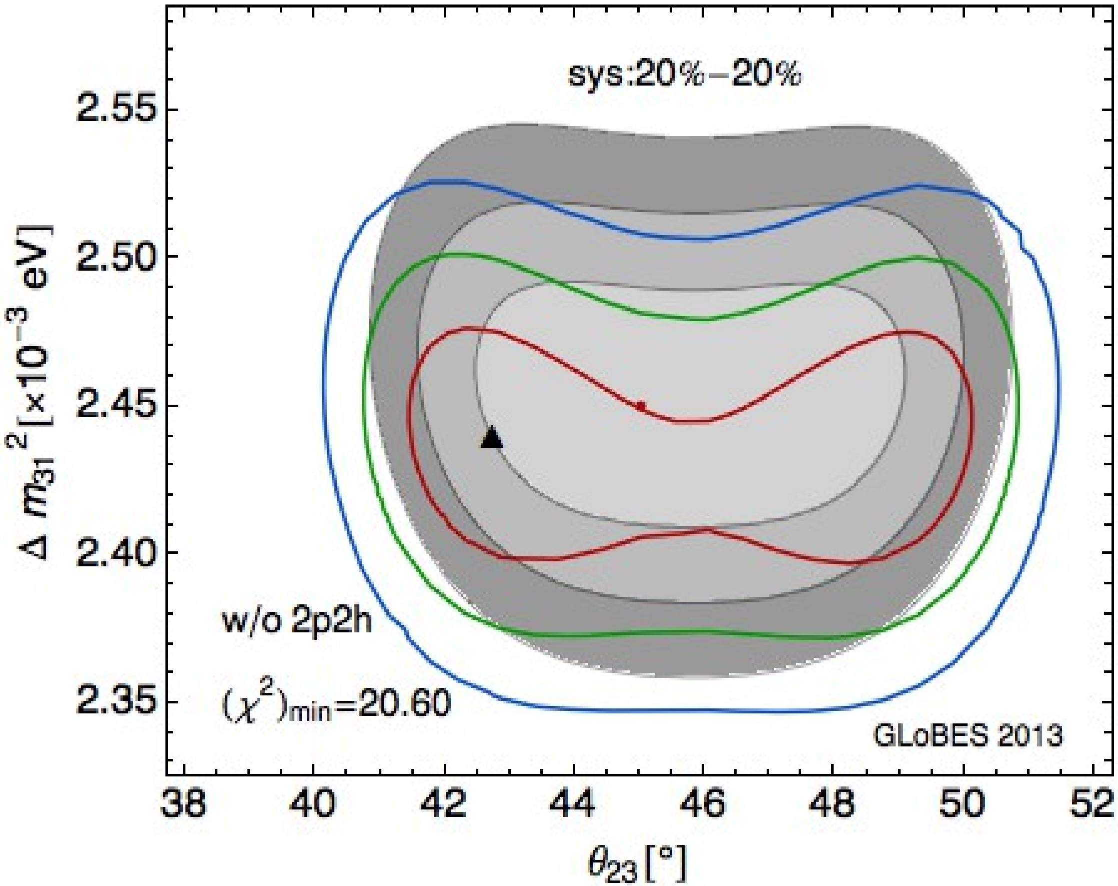




Coloma and Huber, 1307.1243 [hep-ph]

Toy model

Even if we get all FSI right except 2p2h corrections...



Coloma and Huber, 1307.1243 [hep-ph]

Conclusions (I)

- The most relevent systematics on appearance experiments are those related to cross sections
  - Unavailability of final flavor at the near detector may be a problem
- Systematic effects may be kept under control under several assumptions:
  - no flux shape uncertainties
  - no cross section shape uncertainties
  - disappearance data can be used to reduce uncertainties in appearance

Conclusions (II)

- Here we have shown some results for a toy model doing a very simple fit to just one angle and one mass splitting
  - We find a large impact on the determination of the mixing angle, which disfavors maximal mixing
  - There is a significant bias on the mass splitting as well
- Even if we get all FSI interactions correctly, failure to include 2p2h effects properly will already induce significant bias

Outlook

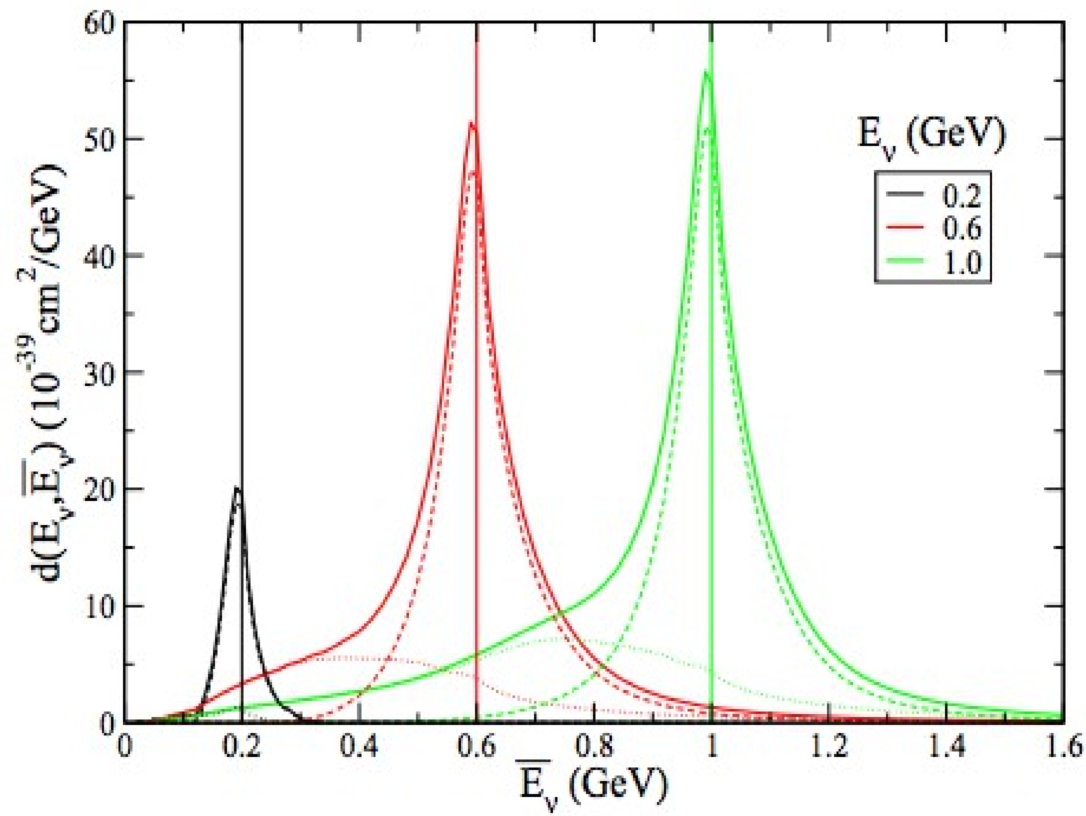
- There is a lot of work to do:
  - What is the effect for a LAr detector?
  - What about the differences between different event generators (NUANCE, GENIE, NEUT, NuWro)?
  - What about differences between different target materials?
  - Effect in antineutrino channels? What is the effect on CP violation searches?

A detailed analysis needs to be done for each experiment in order to evaluate it properly

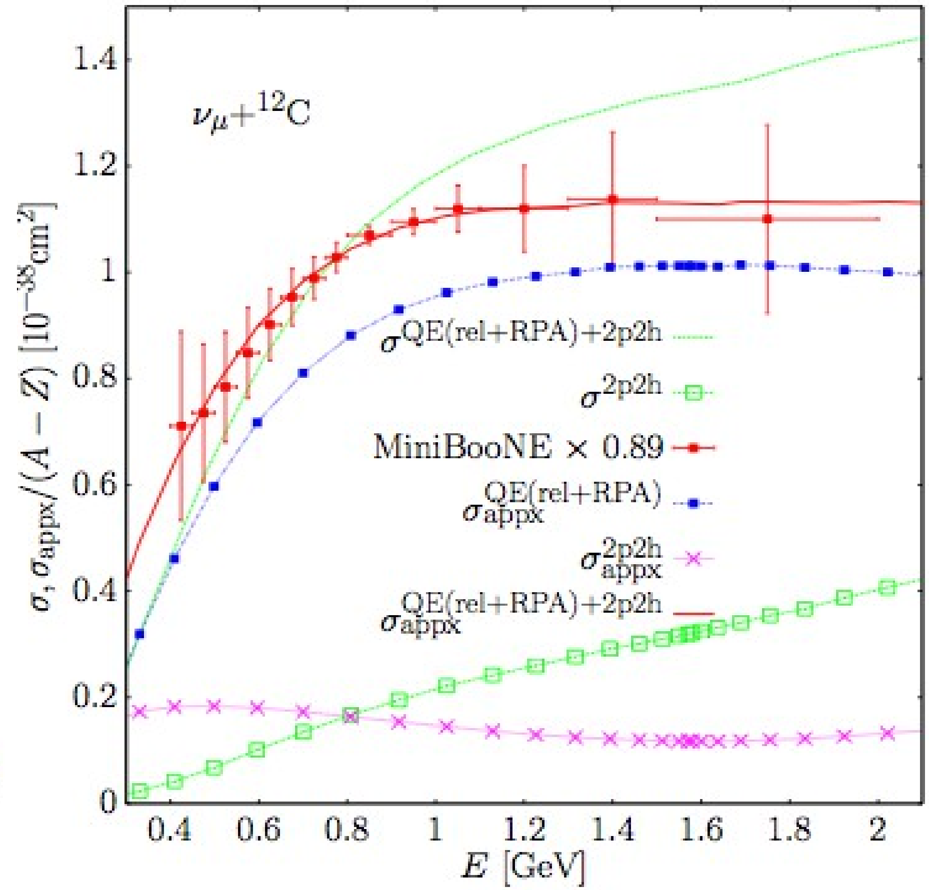
Thank you!

Backup

Multinucleon interactions



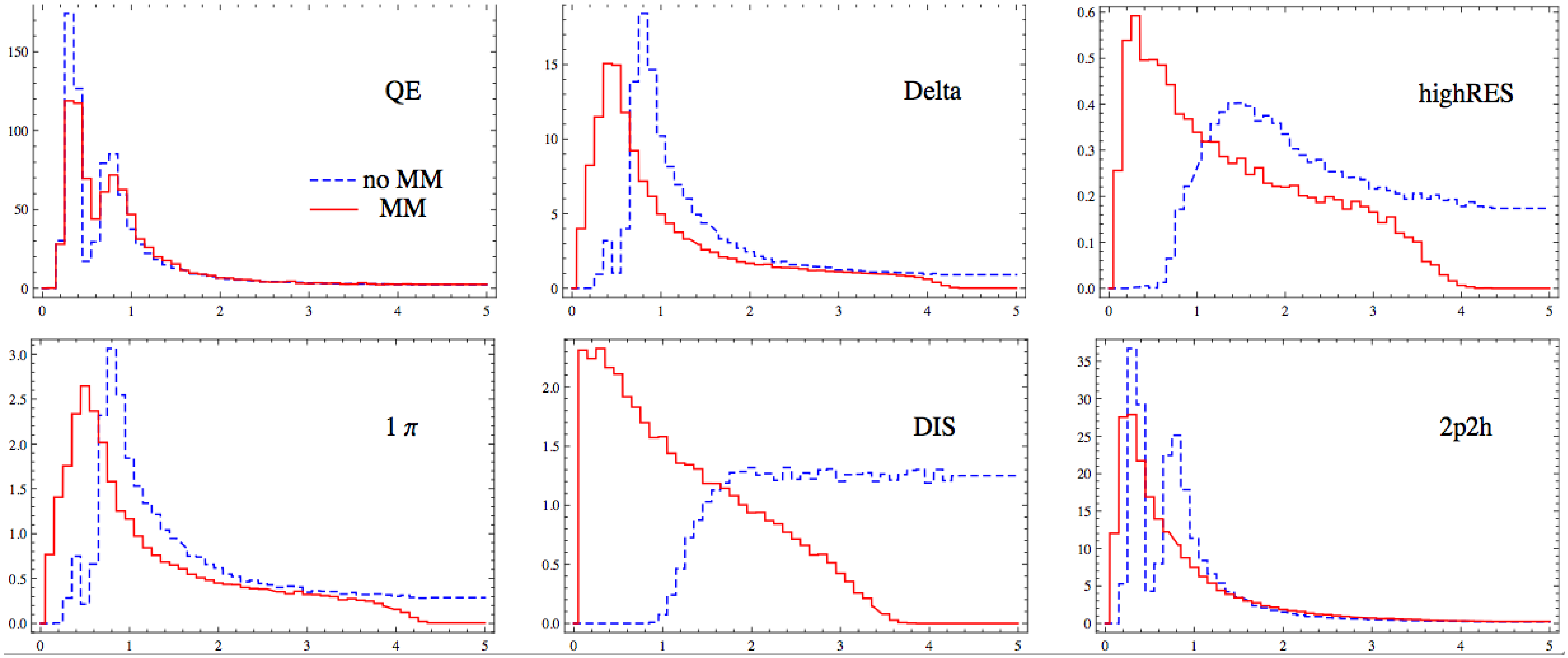
Martini, Ericson, Chanfray,
1211.1523 [hep-ph]



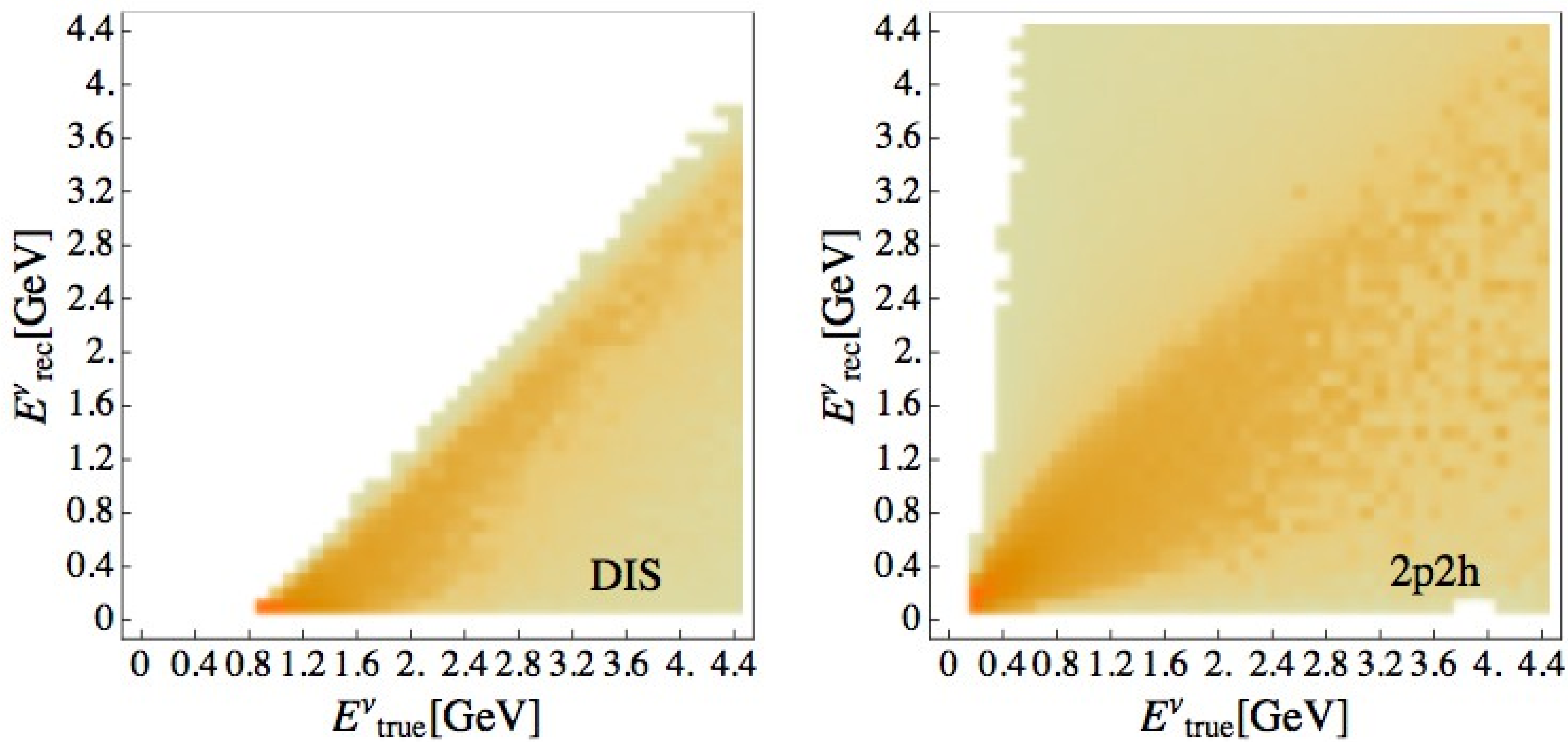
Nieves, Sanchez, Ruiz Simo, Vicente Vacas,
1204.5404 [hep-ph]

See talk by Nieves and Sobczyk

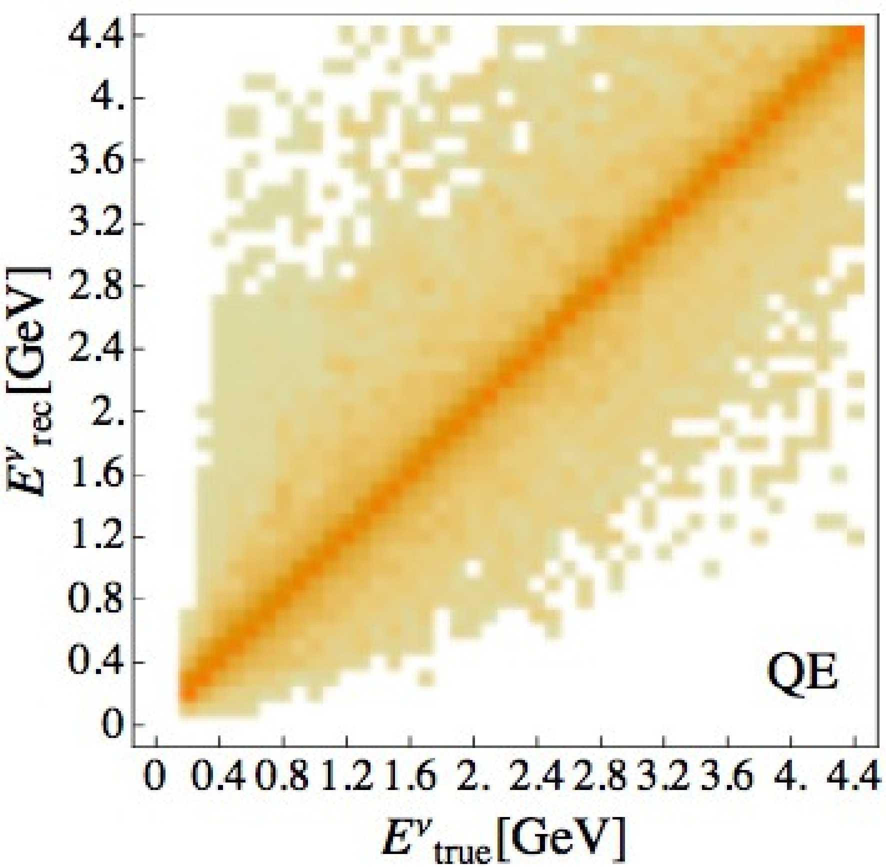
Event distributions

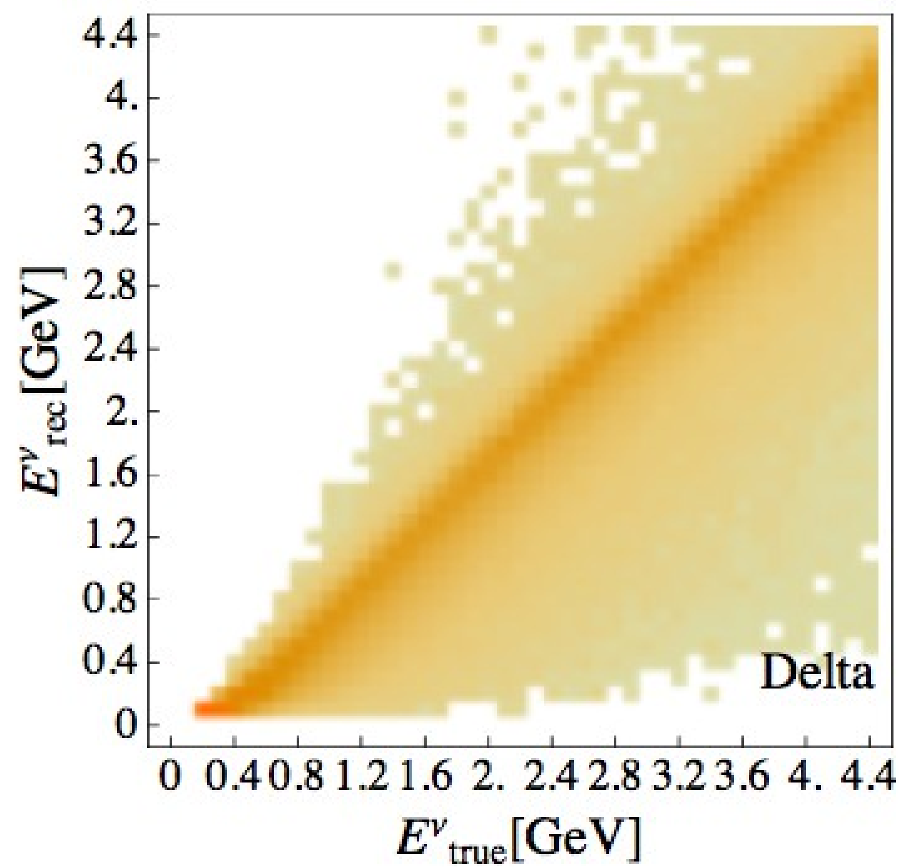


Migration matrices

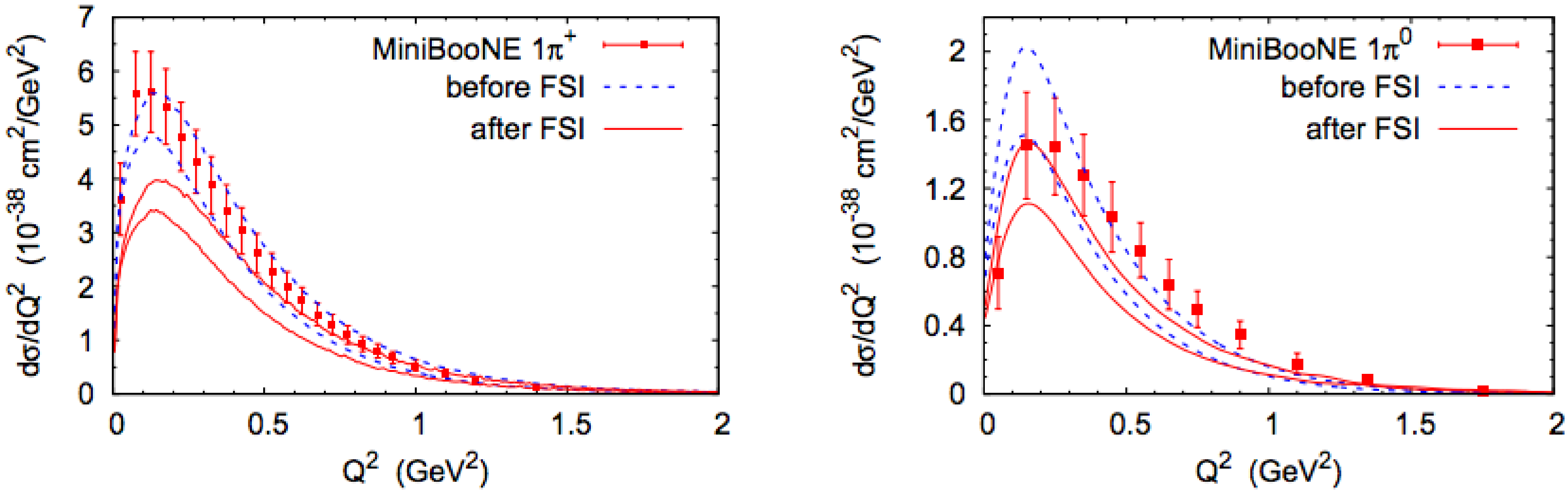


Migration matrices



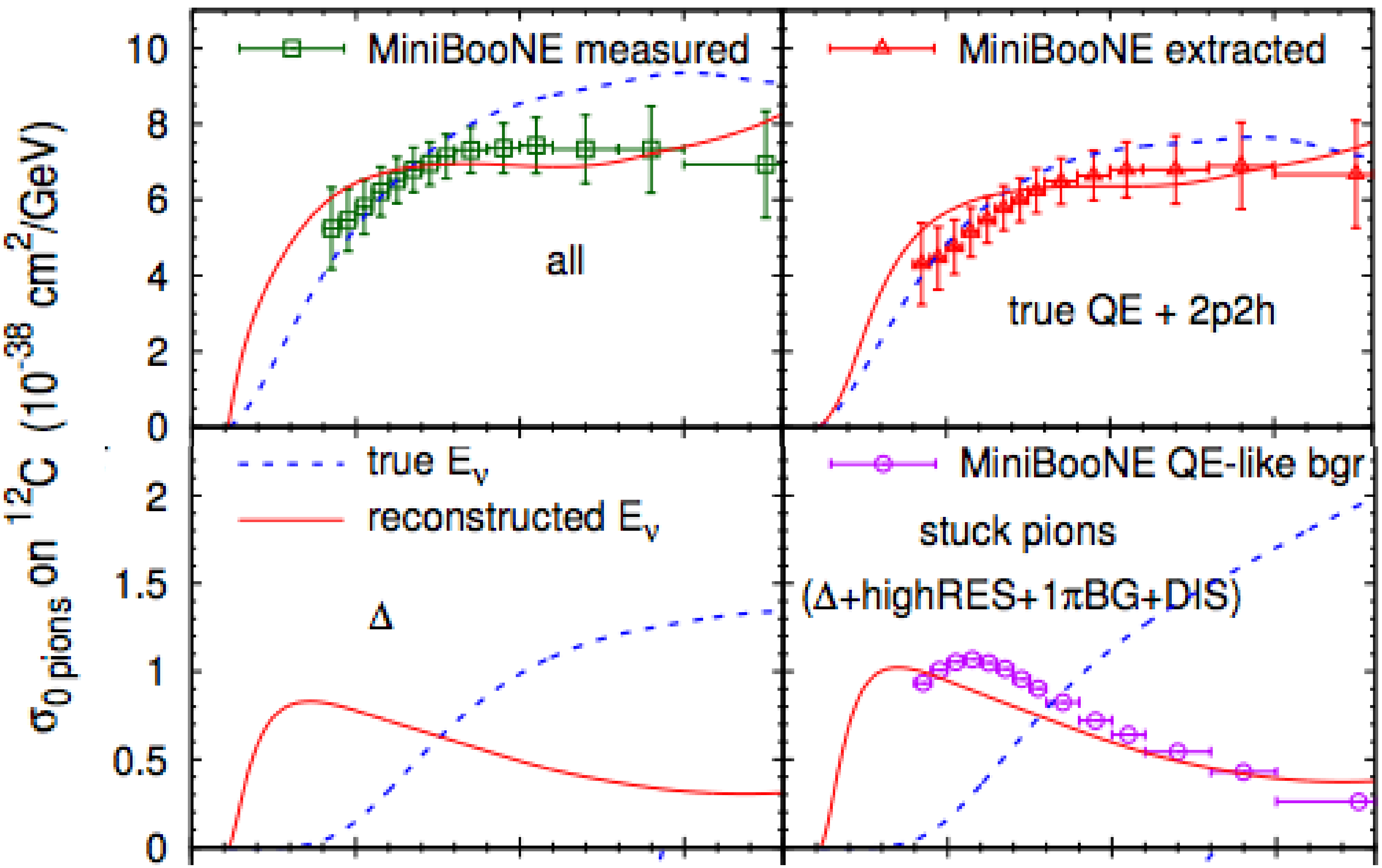


End of the story?



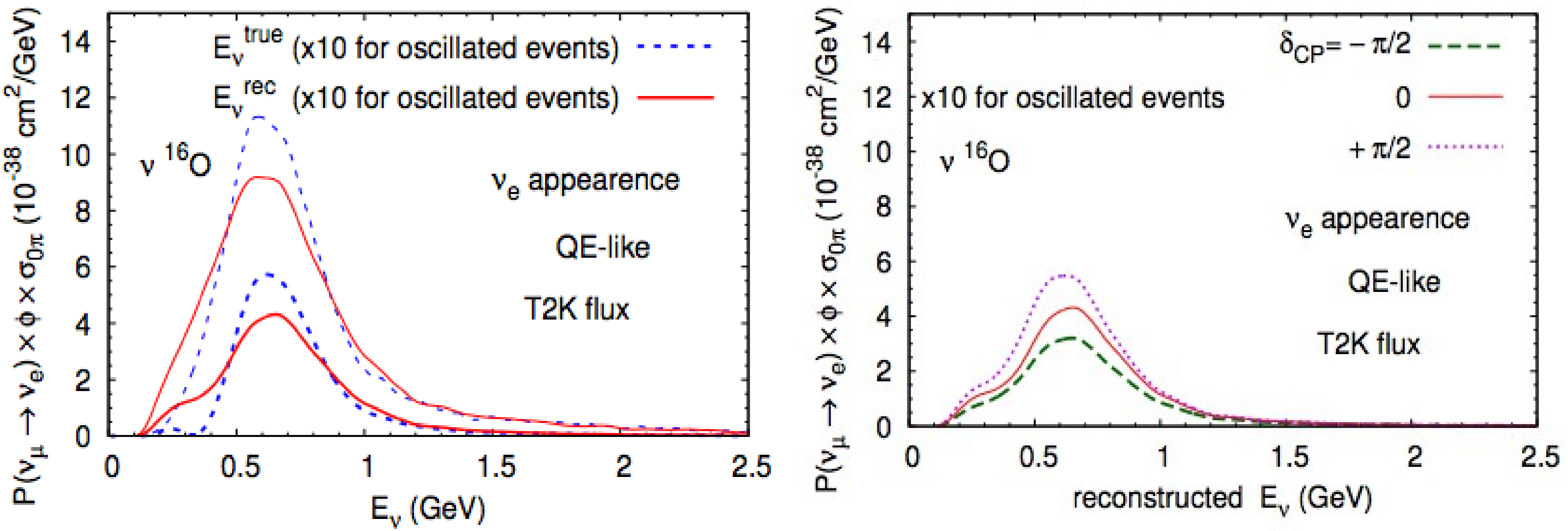
Lalakulich and Mosel, 1210.4717 [nucl-th]

Nuclear effects and FSI



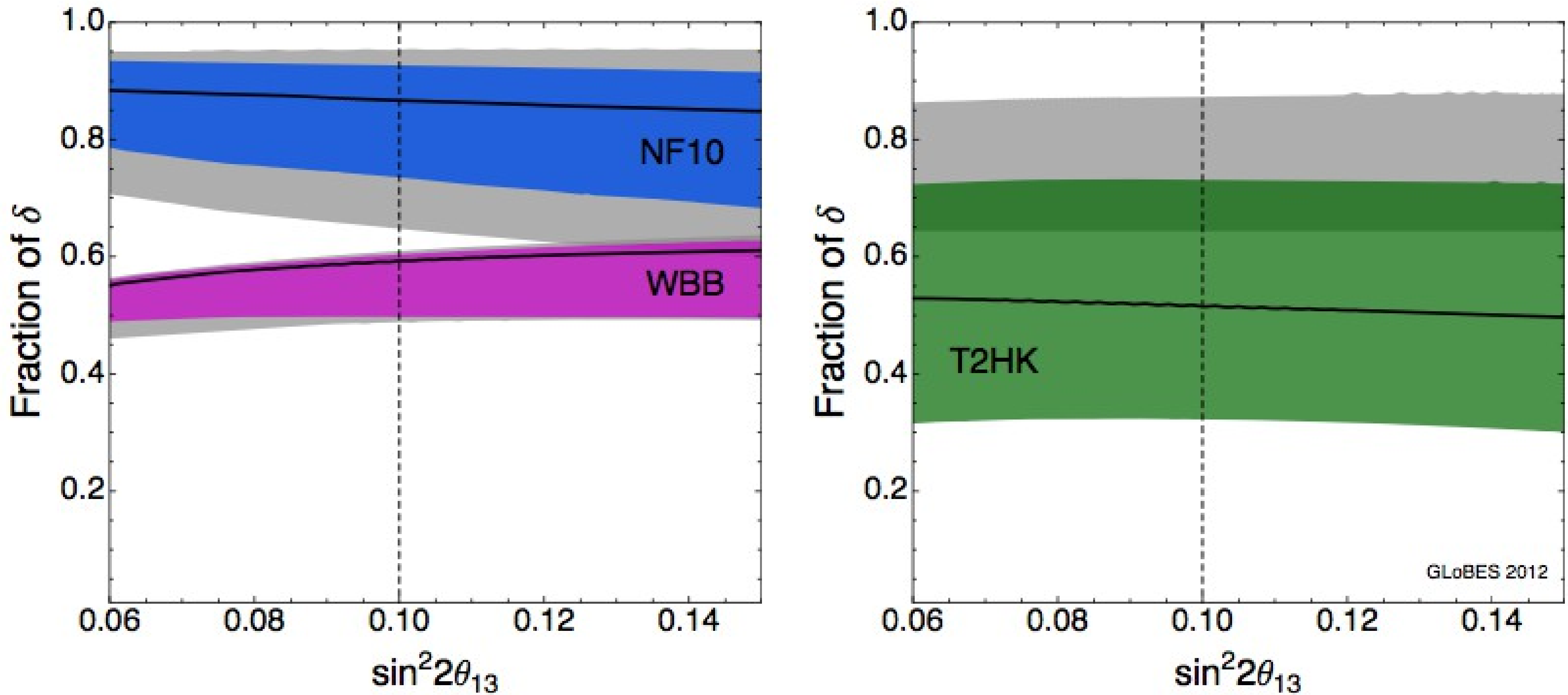
Lalakulich, Mosel and Gallmeister, 1208.3678 [nucl-th]

Nuclear effects and FSI



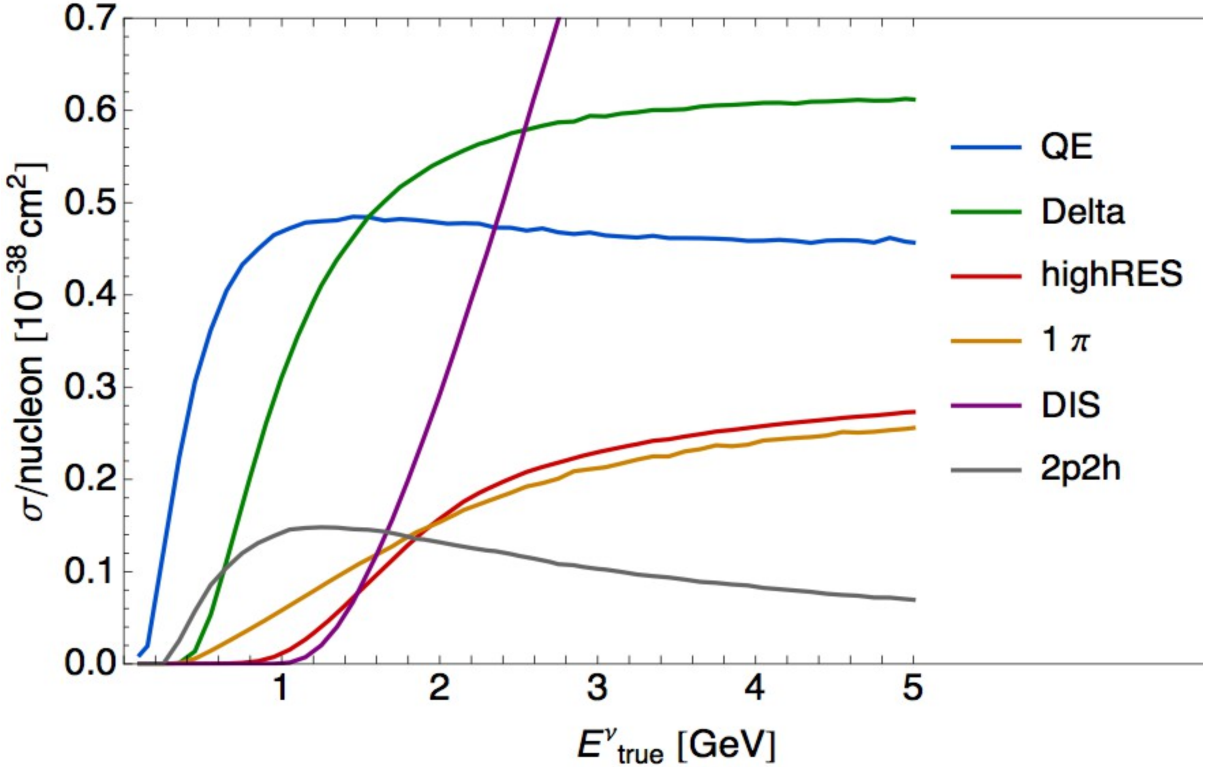
Lalakulich, Mosel and Gallmeister, 1208.3678 [nucl-th]

Impact of systematics on CPV



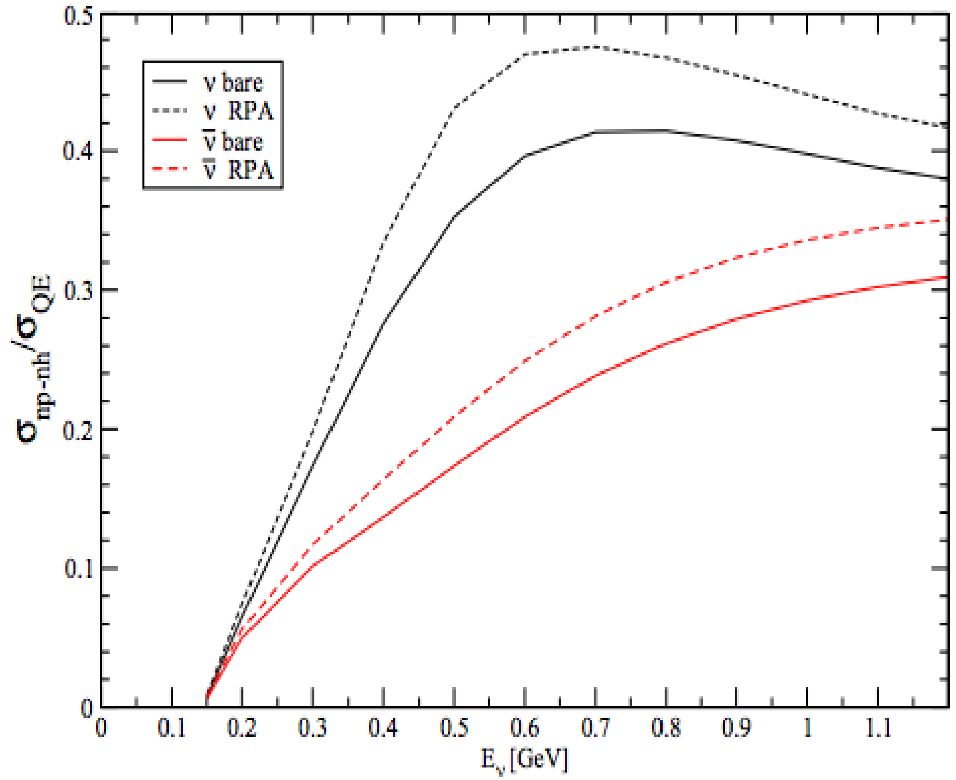
Coloma, Huber, Kopp, Winter,
1209.5973 [hep-ph]

Toy model



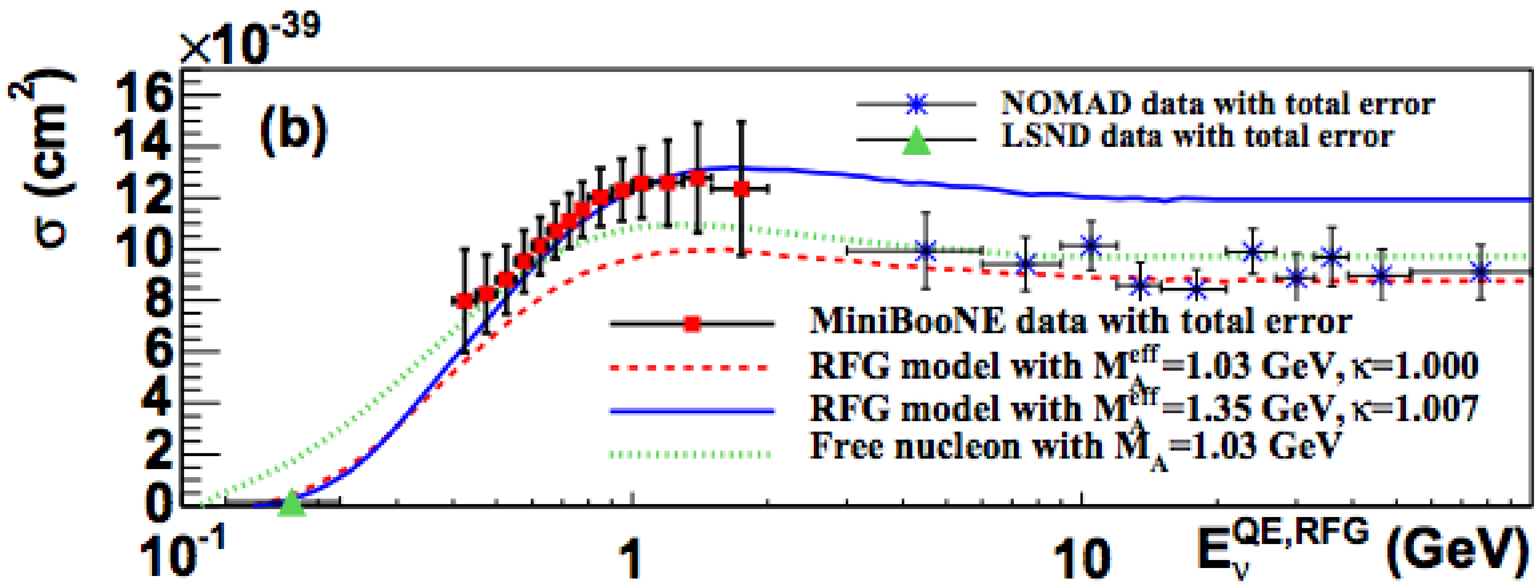
Lalakulich, Mosel and Gallmeister, 1208.3678 [nucl-th]

Multinucleon effects



Martini, Ericson, Chanfray, Marteau,
1002.4538 [nucl-th]

QE cross section at MiniBooNE



The reported cross section is significantly larger ($\approx$ 30% at the flux average energy) than what is commonly assumed for this process assuming a relativistic Fermi Gas model (RFG) and the world-average value for the axial mass, $M_A = 1.03$ GeV [9]. In addition, the Q^2_{QE} distribution of this data shows a significant excess of events over this expectation at higher Q^2_{QE} even if the data is normalized to the prediction over all Q^2_{QE}. This leads to an extracted axial mass from a "shape-only" fit of the Q^2_{QE} distribution of $M_A^{\rm eff} = 1.35 \pm 0.17$ GeV, significantly higher than the historical world-average value.

See Schmitz's talk and WG2 paralell sessions on Mon-Tue

MiniBooNE coll., 1002.2680 [hep-ex]